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Model Execution and Evaluation Tool: Current Status and Initial MM5 Ensemble Member Analysis Results

by Stephen F. Kirby

ARL-MR-577 December 2003

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ARL-MR-577 **December 2003**

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
12-01-03	Memorandum Report	Oct 2002 – Sep 2003

4. TITLE AND SUBTITLE Model Execution and Evaluation Tool: Current Status and Initial MM5 Ensemble Member Analysis Results	**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Stephen F. Kirby	**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Computational Information Sciences Directorate Battlefield Environment Division (ATTN: AMSRL-CI-EB) White Sands Missile Range, NM 88002-5501	**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-MR-577
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory 2800 Powder Mill Road Adelphi, MD 20783-1145	**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)** ARL-MR-0577

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

A web-based mesoscale model analysis tool built with Java Server Pages is under development. With this tool a user is able to 1) run either the MM5 or WRF mesoscale model in standalone mode or as an ensemble on a Linux cluster; 2) generate error statistics for both the surface and upper air regions based on the model output and "truth" data derived from a mesonet (for the surface analysis) and raobs (for the upper air analysis); 3) store the results in an XML database; and 4) display error statistic results employing VisAD-based routines. In addition, a java web service application has been developed which allows a client on a remote machine to query the XML database on the server for model statistics.

15. SUBJECT TERMS

Web Application, Java Server Pages, Java Web Service, XML, Mesoscale Model Ensemble, Statistical Analysis

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	SAR	38	Stephen F. Kirby
Unclassified	Unclassified	Unclassified			**19b. TELEPHONE NUMBER** (*Include area code*) (505) 678-7474

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Preface

The Model Execution and Evaluation Tool (MEET), a web-based software capability, is under development. With this tool, users can run both the Mesoscale Model (Version) 5 (MM5) and the Weather Research and Forecasting (WRF) model and generate statistical analyses. The ability to store statistical results in an XML database as well as view statistical results through the web interface are features currently being integrated. The computer platform is a Linux cluster with 16 dual-processor nodes. The software providing the parallelism for the MM5 test runs is Scali Message Passing Interface (MPI). Parallelism in the case of WRF is created by Message Passing Interface Chameleon (MPICH), a freeware software package.

Given this significant computing capability, a four-member, multi-analysis MM5 model ensemble is being run and analyzed. The four members consist of MM5 using four different coarser resolution models for initialization. The four models are the AViatioN (AVN) model (1º horizontal resolution), Eta (40 kilometer horizontal resolution), the Medium Range Forecasting (MRF) model (1º horizontal resolution) and the Navy Operational Global Atmospheric Prediction System (NOGAPS), also at 1º horizontal resolution.

The execution time for a four-member MM5 model "multi-analysis ensemble"–using three grids (doubly nested) of sizes 55x65x23, 36km grid spacing, 55x55x23, 12km grid spacing, and 85x85x23, 4km grid spacing, with a forecast period of 24-h–is approximately two hours. The follow-on model to MM5 is the WRF model. An execute capability for WRF has been added to MEET and analysis algorithms for WRF will be developed as well.

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Acknowledgements

The author would like to thank Dr. Teizi Henmi of the U.S. Army Research Lab for providing an initial version of the bilinear interpolation FORTRAN code used in the surface statistical analysis.

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Summary

The model execution and evaluation process has many components: gathering input datasets, reconfiguring model domains, running a model or model ensemble, as well as gathering truth datasets to statistically analyze the accuracy of the model output. These tasks can be very time-consuming. As a means of eliminating a significant amount of this manual effort and to allow the user to concentrate on model analysis, a Java Server Pages based software module called the Model Execution and Evaluation Tool (MEET) is being implemented. This report will cover the MEET architecture and will show some sample results. A more extensive data report will be written later.

Java Server Pages were chosen for this web-based tool because of their unique ability to allow one to embed java code within either HTML or XML. This is a powerful paradigm through which one can both generate browser display as well as control external programs, such as the FORTRAN model codes, modules to display statistical output, etc.

The first component in model execution is to obtain the large-scale initialization. What options the user has depends on which model the user wishes to run and in what mode: standalone or as an ensemble. Within MEET, Mesoscale Model (Version) 5 (MM5) can be run in either a standalone mode or as a four-member multi-analysis ensemble. An ensemble is being investigated to determine if it provides more accurate parameters in the model output than running the model standalone.

If a user wishes to execute a Weather Research and Forecasting Model (WRF) run, they may opt for either AViatioN (AVN) or Eta as the large-scale initialization data whereby an anonymous FTP is automatically initiated to get the appropriate datasets from the National Center for Environmental Prediction (NCEP).

Once the model runs have completed and the truth data sets have been acquired, statistical analysis may begin. For model surface analysis, the user will have access to mesonet data from the inner-mountain west region. For upper air analysis, raobs from worldwide locations are made available through the web interface.

After the statistical analysis is complete, the results will be stored in an XML database. A Java web services designed specifically for MEET enables a client to query this XML database for specific statistics on the model output.

1. Introduction

The Model Execution and Evaluation Tool (MEET), a web-based software tool, is currently under development. The MEET has recently been moved from a single processor Linux platform to a 16-node (each node with a dual processor) Linux cluster. Users are provided options to:

- Execute either of two mesoscale models: Mesoscale Model (Version) 5 (MM5) or the Weather Research and Forecasting (WRF) model. MM5 can be run using either archived Navy Operational Global Atmospheric Prediction System (NOGAPS) data (1997-present) or as a four-member, multi-analysis ensemble using the latest 0000 Universal Time Coordinates (UTC) model runs of AViatioN (AVN), Eta, Medium Range Forecasting (MRF) model, and NOGAPS for model initialization. WRF currently runs using a single nest only. The user is given the option of running WRF using either the latest 0000 UTC AVN or 0000 UTC Eta model runs.

- Generate statistical output from the model outputs. Statistical analyses for temperature, relative humidity, and the u- and v-components of the wind are available, both for model output near the surface and at higher levels. The truth data used for the surface statistical analysis is from the Mesowest mesonet located in Utah and the adjoining states. For the upper air statistical analyses, raobs are used as truth.

- Convert the statistical output files to XML and store in an XML database.

- View the statistical analysis data. Bias plots and scatterplots of temperature, relative humidity, and the u- and v-components of the wind can be created.

To ensure that the best meteorological model data is disseminated for Army purposes, model evaluation is carried out at the U.S. Army Research Laboratory on an ongoing basis. Model evaluation has many facets:

- Data collection–both to initialize the models and to verify them.

- Model execution.

- Analysis of the model results–which is realized both in statistics and graphical plots.

- Storage of the statistical results in a database (not always done but is beneficial for historical studies or in looking for trends). This allows a client to query the database for model statistics. Storage of the model output itself will soon be quite feasible because of rapid increase in drive capacities.

With the development of the MEET, all of these components will be available through a web interface. This tool is designed to run models both on an individual basis and as ensembles.

2. Methodology

The only MM5 large-scale initialization model that has a historical dataset archive readily available is NOGAPS. Through MEET, the user has the option of running MM5 using NOGAPS datasets from 1997 to present. In addition, MM5 can be run using real-time AVN, Eta, or MRF data from the anonymous FTP site at NCEP. The WRF has been designed to run using either AVN or Eta model data, which is available in real-time from the NCEP anonymous FTP site. Ensembles can be run in three different modes: 1) multi-analysis; 2) multi-model; or 3) multi-model, multi-analysis. The ensemble currently available in MEET is the MM5 multi-analysis ensemble and consists of four members, in which MM5 has been initialized with AVN, Eta, MRF, and NOGAPS data. Multi-model and multi-model/multi-analysis ensembles will be feasible when the WRF model is redesigned to allow nesting of domains.

The web interface is built around Java Server Pages (JSP), which allows java code to be embedded within HTML or XML. Through the JSP, calls are made to various programs and scripts to carry out user requests. For example, if the user requests a MM5 run using NOGAPS, the MM5 FORTRAN code is recompiled to account for the configuration the user requests (i.e., the number of nests). Then the JSP will call on a number of scripts to process the NOGAPS data in preparation for the MM5 run before finally starting the MM5 run. Scali MPI provides the parallelism in software for the MM5 model runs, while for WRF, Message Passing Interface Chameleon (MPICH) is used.

Statistics may be generated both for surface analysis and upper air analysis. The surface analysis through MEET is currently restricted to the inner-mountain western U.S. This is because the only freely available real-time mesonet FTP data source is from Mesowest, which provides a continuous live feed of surface parameters. Upper air data analysis may be carried out almost globally with the availability of raobs from every continent through a University of Wyoming HTTP site: http://weather.uwyo.edu/upperair/sounding.html. Currently available statistics to delineate the accuracy of MM5 model output temperature, u- and v-components of the wind, and relative humidity (which is actually derived from other model parameters) include:

- bias
- mean error
- mean absolute error
- root mean square error

- ensemble spread
- ensemble dispersion
- rank correlation

Through the use of a java-based graphics development toolkit called Visualization for Algorithm Development (VisAD), routines have been developed by the author to display model outputs versus truth as scatterplots, providing the user a view of model output quality. Bias plots through VisAD routines are also available.

For the MM5 ensembles, a means of fusing the ensemble members is being investigated, whereby each ensemble member parameter is assigned a weight based on the parameter accuracy over the last 24-h forecast. The more accurate the ensemble member parameter is for that period, the higher the weight it will be assigned. The four weights of a particular parameter from the four-ensemble members total to a value of one. The ensemble members are then “fused” together on a parameter-wise basis given the pre-derived weights. Although sample weight values have been calculated for ensemble runs, the final fusion process has not been tested.

A means for a client to seamlessly obtain model output statistics from the XML database on the server has been developed through the application of a Java Web Service. A web service is defined as the ability of one software application to communicate with another application via web protocols without direct human intervention. With MEET, the client can request specific model output statistics for a given model, output parameter, and forecast lead time.

The ability to both obtain model inputs and execute the mesoscale models (MM5 and WRF) through a web interface has been built. Furthermore, the user is able to obtain “truth” data from the Mesowest mesonet and perform statistical analyses on the MM5 output. In addition, the ability to run MM5 as a multi-analysis ensemble and generate statistics on the ensemble output is available. Lastly, the WRF model has been recently incorporated and may be run using either AVN or MRF model data for large-scale initialization. Statistical routines to analyze WRF output need to be implemented next.

3. MEET Architecture and Tools Available

3.1 The Server Side

3.1.1 Ensemble Modeling Background

Significant computing capability available with a 32-processor Linux cluster made it feasible to examine MM5 run as an ensemble. There has been a progression from deterministic forecasting to stochastic dynamic forecasting to ensemble modeling. In deterministic forecasting, one takes the initial conditions and integrates the model equations forward. In this case, the initial conditions are assumed to be the true state of the atmosphere. However, this cannot be since there are instrument errors and possible errors in interpolation of data. With stochastic dynamic forecasting, the prognostic equations are modified by adding terms to account for the uncertainty in the initial conditions. These terms are carried throughout the integration, leading to a distribution of solutions.

In the scheme used here, MM5 is run as a multi-analysis ensemble. It is multi-analysis in the sense that it is initialized with four different coarser scale models: the AVN model, the Eta model, the MRF model, and the NOGAPS model. Combining the ensemble members allows for smoothing of features that are in disagreement between the individual forecasts and the retention of features that are similar. Gerding and Myers have proposed fusing the ensemble members in the following way (*1*):

$$X_f = \left(\sum_{j=1}^{n} w_{jf} c_{jf} (X_{jf} + b_{jf})\right) / \left(\sum_{j=1}^{n} w_{jf} c_{jf}\right) \tag{1}$$

where

f = variable

X_f = fused forecast

X_{jf} = input forecast

c_{jf} = associated confidences

w_{jf} = weights

b_{jf} = biases

The fused forecast is the sum of the bias adjusted input forecasts, modified by some weight and confidence. For simplification, the bias is assumed to be zero and the confidence assumed to be one. The weights are calculated according to the Newbold-Granger methodology, as follows:

$$w_{jf} = [(\sum_{t=T-\nu}^{T-1} (X_{tf} - X_{jf}))]^{-2} / \sum_{k} [(\sum_{t=T-\nu}^{T-1} X_{tf} - X_{kf})]^{-2} \tag{2}$$

where

X_{tf} = truth for the forecast

X_{jf} = input forecast

ν = some time window

k = refers to the respective ensemble members

Because each weight is normalized by the sum of the errors for a given parameter over all the ensemble members, the weights for a given parameter across all ensemble members sum to one.

3.1.2 Generating Model Runs

The server side of MEET refers to the actions taking place on the 32-processor cluster. A user providing input to the web interface of MEET (fig. 1) is communicating information directly to the Java Server Pages modules.

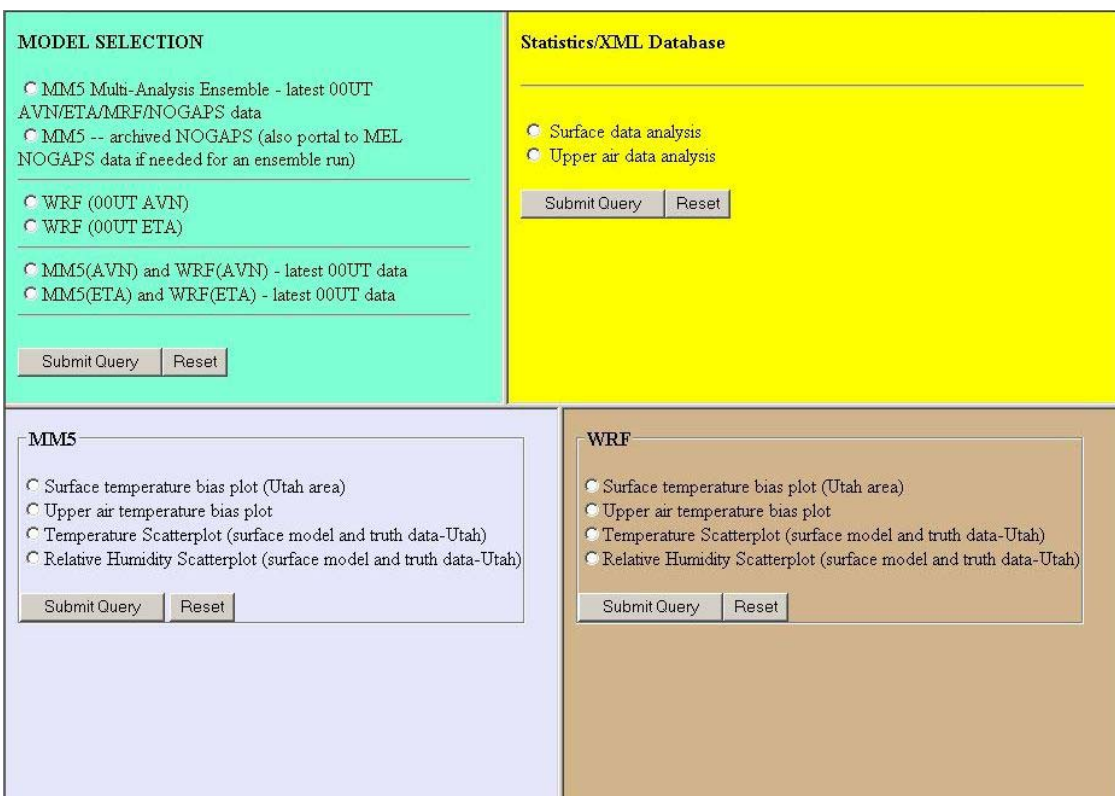

Figure 1. Initial Web Interface to MEET.

The user has six options in the **MODEL SELECTION** frame:

1. MM5 Multi-Analysis Ensemble–latest 00UT AVN/Eta/MRF/NOGAPS data
2. MM5–archived NOGAPS
3. WRF (00UT AVN)
4. WRF (00UT Eta)
5. MM5 (AVN) and WRF (AVN)–latest 00UT data
6. MM5 (Eta) and WRF (Eta)–latest 00UT data

If the user selects option 1, an anonymous FTP session to NCEP will immediately begin acquiring the latest 0000 UTC valid run time of the AVN and Eta analysis, the 3-h, 6-h, 9-h, 12-h, 15-h, 18-h, 21-h, and 24-h forecasts. For the MRF, the latest 0000 UTC valid run time analysis, 12-h, and 24-h forecasts, will be acquired. There is no anonymous FTP site available for NOGAPS. Instead, the user should select MM5-archived NOGAPS, at which point an option to request NOGAPS data will be given. The latest 0000 UT valid run time analysis, the 6-h, 12-h, 18-h, and 24-h forecasts, should be obtained. Once all of the data sets are on the server, an MPI run begins, utilizing the 32 processors. The model configuration consists of three domains, with two inner nests. The outer domain is 55x65x23 points at 36km grid spacing. The first nested domain is 55x55x23 points at 12km grid spacing while the innermost nest is 85x85x23 points at 4km grid spacing. Currently, there is no provision to set the coarse domain center because surface verification data is only available from the inner-mountain west region, so the coarse domain is centered approximately over Salt Lake City, Utah. The ability for the user to set the domain center will likely be made available in a future revision when new verification data sets are identified.

Option 2 in the **MODEL SELECTION** frame lets a user select any NOGAPS data set from the Master Environment Library (MEL), dating back as far as 1997, to use as initialization data for MM5 (fig. 2).

Figure 2. Setting Up a MM5 Run Using Archived NOGAPS.

The user may request NOGAPS data (through MEL) and pick up the requested NOGAPS data from a Naval Research Laboratory (NRL) FTP pickup site (fig. 3).

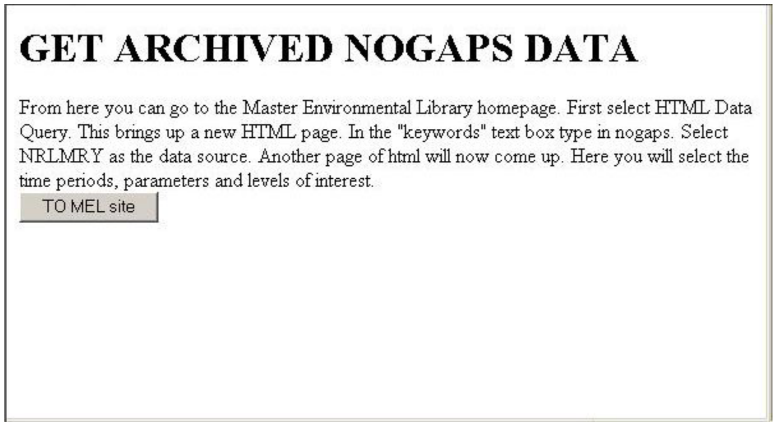

Figure 3. Screen to Obtain NOGAPS Data.

Once the data is on the system, the user chooses **upload nogaps** (fig. 4). The user will be able to browse their system and then will click upload to move the data onto the server.

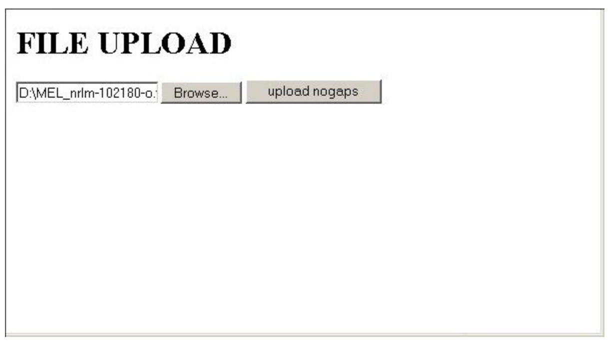

Figure 4. File Upload Screen.

Lastly, the user selects “set up a mm5 run,” which allows for specifying the run-time window, model domain center point, and number of grids (fig. 5).

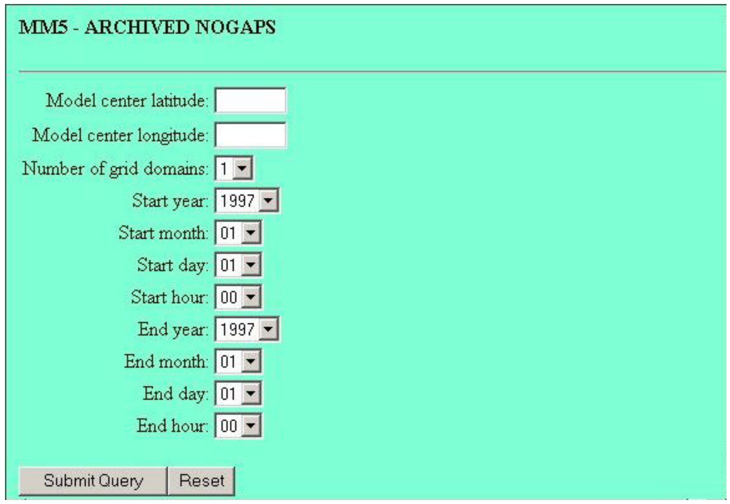

Figure 5. User Screen to Setup for a MM5 Run.

If option 3 is selected in the **MODEL SELECTION** frame, an anonymous FTP begins for the latest 0000 UTC valid run time of the AVN model and as with the ensemble in option 1, the 00-24-hr forecasts at 3 hour intervals are obtained. The WRF Standard Initialization (WRFSI) routines are called next to interpolate (both horizontally and vertically) the AVN data onto the WRF grid for use as initial and lateral boundary conditions. Finally, the WRF model is ready to be run. Parallelism is created for the WRF runs by the use of Message Passing Interface Chameleon (MPICH), a freeware package.

Option 4 mirrors option 3 except that the initial and lateral boundary conditions are set using Eta model data. Options 5 and 6, although not implemented yet, will allow for side-by-side comparisons of MM5 and WRF, using AVN and Eta as initialization data. Once WRF has a nesting capability, it will be possible to have side-by-side comparisons with a high-resolution inner nest.

3.1.3 Statistical Generation

The second frame in the initial MEET web interface is **Statistics/XML database**. Here, the user has the option to begin either surface or upper air analysis. If the user selects **Surface analysis**, the options are to: (1) download Mesowest mesonet data from U of Utah anonymous FTP site; (2) upload this data to the server; (3) generate the surface statistics given some MM5 model output and the newly acquired mesonet data; and (4) store the statistical results in the eXist XML database as seen in figure 6.

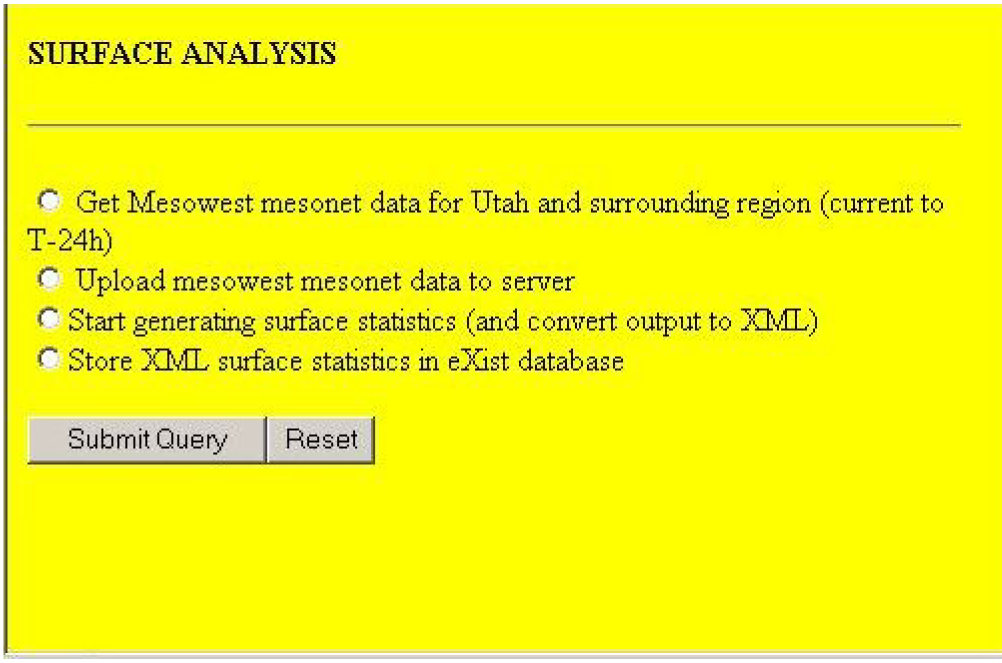

Figure 6. Surface Analysis Options.

The other option is to analyze the higher levels of the model output using Radiosonde observation (raob) data as truth. When the user selects **Upper air data analysis**, the options generally mirror the surface data analysis options, except that the truth data, raobs, will be obtained via http to a University of Wyoming Internet site (fig. 7).

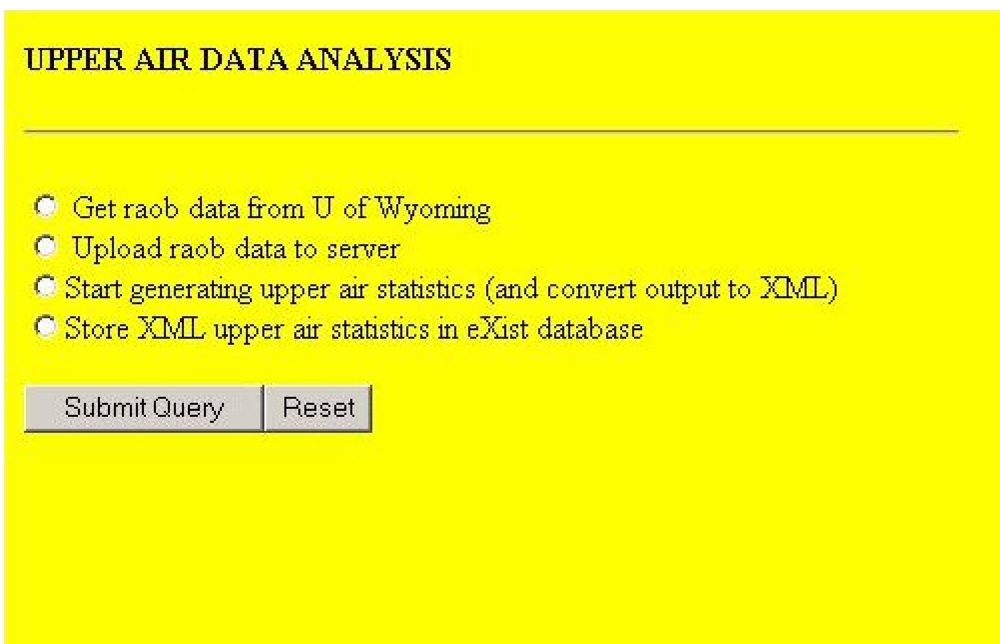

Figure 7. Upper Air Data Analysis.

3.1.4 Display of Statistics

The bottom two frames of the initial MEET web interface (fig. 8), with the **MM5** frame (left) and the **WRF** frame (right), allow for the display of VisAD generated graphics of the statistical analysis.

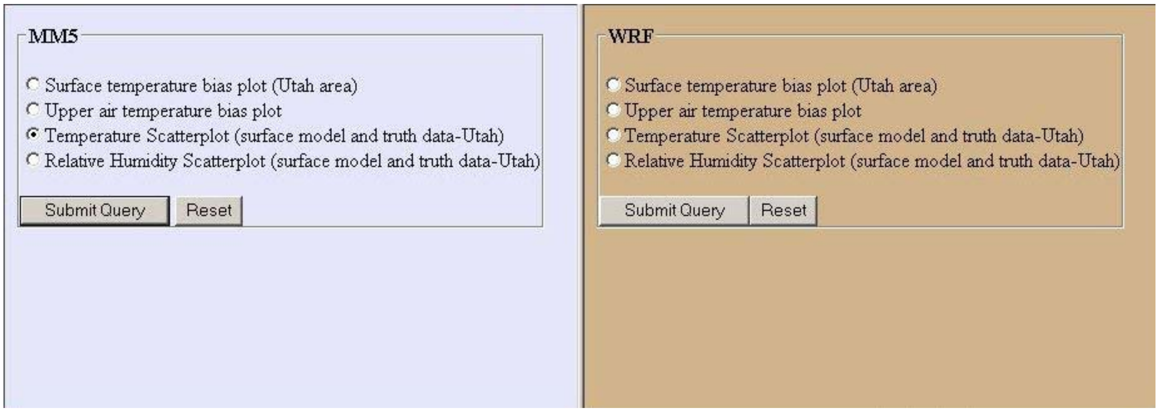

Figure 8. Two Frames Where a User May View Either MM5 or WRF Statistics.

In figure 9, the scatterplot is shown in the left frame. Model temperature is represented along the x-axis, while the y-axis represents (mesonet) station temperatures. Here, the JSP has taken the current temperature scatterplot generated and placed it in the **/pics** directory of the JSP tree. The results seen are the surface data from a 22-h MM5-NOGAPS ensemble forecast, 36km grid resolution. Bilinear interpolation has been used to interpolate the model grid data to the station location.

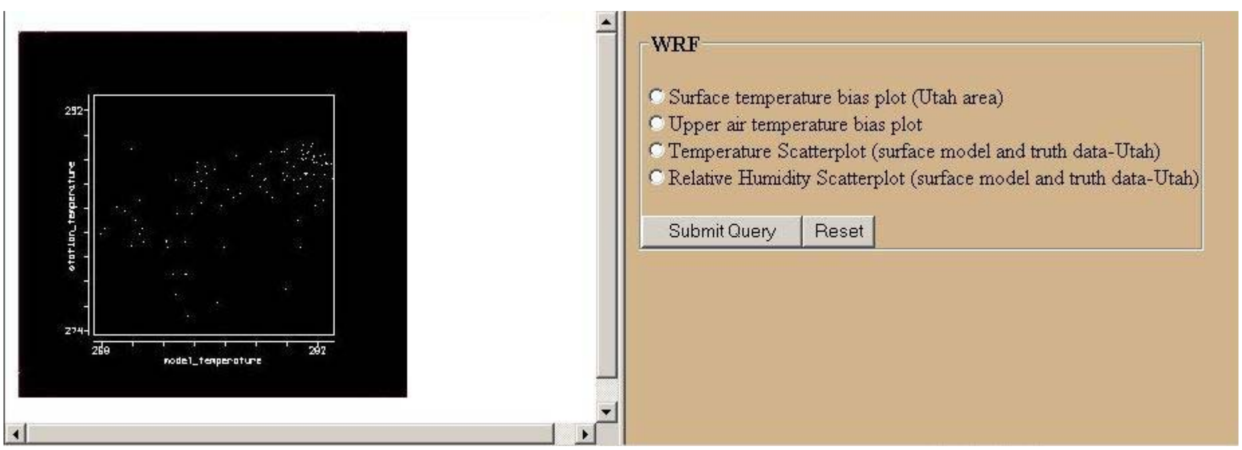

Figure 9. Sample Display of a Temperature Scatterplot.

3.1.5 Statistical Measures Used in MEET

A number of statistical values are calculated within MEET, including some specific for determining the accuracy of the ensemble forecasts (*2*). They are:

1. Bias

$$y_i - o_i \tag{3}$$

where

y_i = model value

o_i = truth value

This measure is used to discover whether the model has tendencies to either over or underestimate any variables.

2. Mean error

$$ME = 1/n \sum_{i=1}^{n} (y_i - o_i) \tag{4}$$

where

y_i = model value

o_i = truth value

n = number of values

3. Mean absolute error

$$MAE = 1/n \sum_{i=1}^{n} |y_i - o_i \tag{5}$$

where

y_i = model value

o_i = truth value

n = number of values

4. Root mean square error

$$RMSE = [1/n\sum_{i=1}^{n}(y_i - o_i)^2]^{1/2} \tag{6}$$

where

y_i = model value

o_i = truth value

n = number of values

5. Ensemble spread

$$SP(f) = \sqrt{\overline{1/N\sum_{n=1}^{N}(f_{i,j}^{n} - \tilde{f}_{i,j})^2}^{i,j}} \tag{7}$$

$$\tilde{f}_{i,j} = 1/N\sum_{n=1}^{N} f_{i,j}^{n}$$

$$\overline{f_{i,j}}^{i,j} = 1/(I*J)\sum_{i=1}^{I}\sum_{j=1}^{J} f_{i,j}$$

where

f = forecast variable

N = number of ensemble members

i, j = indices

I = number of rows

J = number of columns

(Note: The overbar with the i, j indices indicates an average over the entire domain.)

The ensemble spread is the mean squared deviation of the component members from their collective mean and provides a measure of the uncertainty with the forecast. Low spread forecasts will be more predictable. Conversely, high spread forecasts tend to be less predictable because no one forecast has a high probability of verifying (*3*).

6. Ensemble dispersion

$$disp = \sqrt{2[1 - r(f, v)]sd(f)sd(v)} \tag{8}$$

where

r = rank correlation

sd = standard deviation

f = forecast variable

v = corresponding station value

Dispersion error is an indication of phase errors in the forecast as opposed to amplitude errors.

7. Rank correlation

$$r = \sum xy / \sqrt{\sum x^2 \sum y^2} \tag{9}$$

where

x = model value

y = corresponding station value

The rank correlation provides a measure of the linear relationship between 2 parameters.

3.1.6 Conversion of Statistics Output to XML and Storage in XML Database

In order to provide a universal format for the output statistics and also allow them to be stored in an XML database, java routines were written to convert both surface and upper air statistics to XML format. The XML format files are not viewable in the browser until their conversion to HTML format. Java API for XML Processing (JAXP) objects, such as StreamSource and StreamResult, are used to perform this conversion (*4*). An example of such a conversion is shown in figure 10. Here, a “dummy” raob file has first been converted to XML by the Java routines. Next, the JAXP objects apply XML stylesheets to the XML.

Model Evaluation Tool

MODEL: ***MM5-MRF***

Lead Time: 0.0

P	T rmse	T mae	T cc	RH rmse	RH mae	RH cc
1000.0	0.2	0.8	1.8	3.9	0.4	5.7
850.0	0.2	0.8	1.8	3.9	0.4	5.7
700.0	0.2	0.8	1.8	3.9	0.4	5.7
500.0	0.2	0.8	1.8	3.9	0.4	5.7
400.0	0.2	0.8	1.8	3.9	0.4	5.7
300.0	0.2	0.8	1.8	3.9	0.4	5.7
200.0	0.2	0.8	1.8	3.9	0.4	5.7
100.0	0.2	0.8	1.8	3.9	0.4	5.7
50.0	0.2	0.8	1.8	3.9	0.4	5.7
20.0	0.2	0.8	1.8	3.9	0.4	5.7
10.0	0.2	0.8	1.8	3.9	0.4	5.7

Figure 10. Sample Output of a Conversion from XML to HTML Using JAXP Routines and XML Stylesheets.

3.2 The Client Side

A java web service (JWS) has been built so a client can access the XML database on the server to obtain a particular model statistic. A web service gives the ability of one software application to communicate with another software application via web protocols without the need for direct human intervention. The protocol used for messages is the Simple Object Access Protocol (SOAP). Because the client and server communicate back and forth with SOAP-wrapped XML messages, platform independence is achieved. For this effort, the third generation SOAP routines from Apache software, assembled in a package called “Axis,” were used. One tool that ships with Axis is tcpmon, a GUI that allows the user see what is happening “on the wire” between client and server. An example of its use is shown in figure 11. The top half of the GUI displays the client activity. Here, the client resident on a Sun Blade 100 has requested from the XML database on the server, a Linux PC, the 0-hr lead time forecast for the temperature bias of the MM5-MRF ensemble member forecast valid May 12, 2002 0000 UTC.

Figure 11. tcpmon GUI Showing Communication Between a Client, Requesting Statistics from an XML Database, and the Server Response.

The response sent from server to client is seen in the bottom half of the tcpmon graphical user interface (GUI). After traversing the folder tree in the XML database, the java web service finds the value, -9.134689, in the “surface_stats” folder.

Figure 12 shows a screen shot of the GUI being developed, which will provide the client a direct method for utilizing the java web service to query for model statistics. Options to query the database for temperature, wind (root mean square vector error), and relative humidity statistics are available. This GUI is written using Java 2 Standard Edition (J2SE) routines.

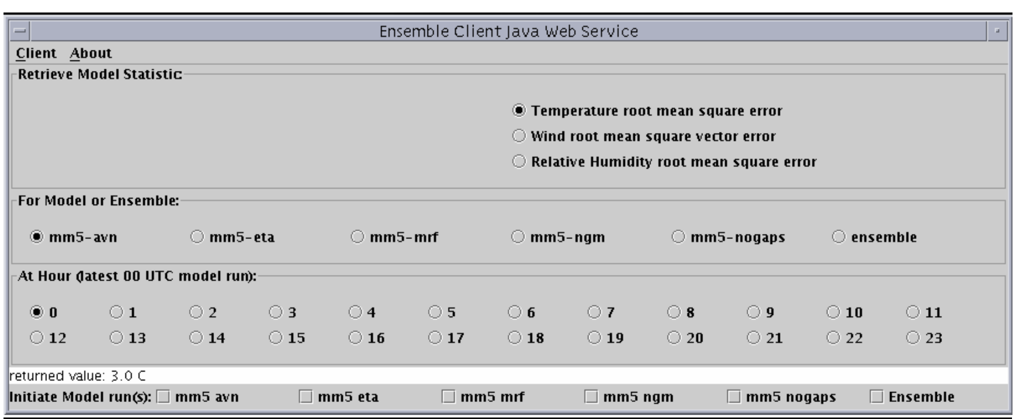

Figure 12. GUI Which Allows Client to Access XML Database on Server.

4. Statistical Results

4. 1 MM5 Ensemble Results

The ensemble members for this study consisted of MM5 initialized with data from four different models:

1. AVN (1º horizontal resolution)
2. Eta (40km horizontal resolution)
3. MRF (1º horizontal resolution)
4. NOGAPS (1º horizontal resolution)

Next, some preliminary analysis is presented to indicate trends seen to date.

4.2 Surface Analysis

Following is a table showing samples of Newbold-Granger weights obtained for an ensemble run using initialization data from 12 May 2003. The weights apply to a surface data analysis. The truth data is the Mesowest mesonet data. Bilinear interpolation is applied to interpolate the model grid to the station locations. As discussed earlier, adding the weights for a given parameter across the members yields a value of one. Also, a higher weight is reflective of the ensemble member producing more accurate output. The trend seen in this table is fairly typical. The MM5-AVN, MM5-Eta, and MM5-MRF members are generally close in their predictions, while the MM5-NOGAPS member tends to lag, especially in temperature prediction.

Table 1. May 12, 2003 Ensemble Run–36 km Grid Spacing.

	MM5-AVN	**MM5-Eta**	**MM5-MRF**	**MM5-NOGAPS**
T	0.30	0.29	0.30	0.11
U-COMP	0.25	0.28	0.26	0.21
V-COMP	0.26	0.28	0.26	0.20
RH	0.26	0.23	0.27	0.24

4.3 Upper Air Analysis

For the upper air analysis, raobs from the University of Wyoming Internet site serve as truth. First, the MM5 utility, “interpb,” is used to convert the MM5 model output from sigma levels to pressure levels. Then an AWK script extracts the mandatory pressure levels from the raob report. Next, at each pressure level, bilinear interpolation is performed to interpolate the model grid data to the raob locations. The area of study is Utah and the surrounding region. For the

outer, coarse grid, nine raobs typically were available. For the inner nest, three raobs typically were available, and for the finest grid, one raob was available.

Preliminary results indicate that for temperature, increasing grid resolution had only a minor effect, and there were only minor differences between ensemble members. The typical mean absolute error was on the order of 1-2º (C), except near the model top of 100mb. Raising the model top to 50mb should reduce these errors. For relative humidity, however, increasing grid resolution did provide more accurate output, and the MM5-Eta ensemble member performed best. Mean absolute errors for relative humidity ranged from two percent to 35 percent. For the u-component of the wind, again, increasing model grid resolution is beneficial. Mean absolute errors for the u-component of the wind ranged anywhere from near zero to 3.5 m/s.

5. Conclusions

A prototype Model Execution and Evaluation Tool has been built. It allows users to: (1) access model initialization data; (2) execute MM5 as a standalone or as a multi-analysis ensemble, as well as execute WRF; (3) access truth data for surface analysis (mesonet data) for the Utah region and for upper air analysis (raobs worldwide); (4) generate statistics for MM5 as a standalone or as an ensemble; (5) store these statistics in an XML database; (6) display statistics using VisAD routines as bias plots and scatterplots, and (7) access the server from some client system to query for statistical results.

Work remains to be done. Generating a multi-model ensemble with the inclusion of WRF can soon be done with the addition of nesting to WRF. Also, analyses need to be carried out to quantify any accuracy gained by using an ensemble as opposed to a single model.

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Acronyms

API	Automated Programming Interface
ARL	Army Research Laboratory
AVN	Aviation (Model)
FORTRAN	Formula Translator
FTP	File Transfer Protocol
GUI	Graphical User Interface
HTML	Hypertext Markup Language
J2SE	Java 2 Standard Edition
JAXP	Java API for XML Processing
JSP	Java Server Pages
JWS	Java Web Service
MEET	Model Execution and Evaluation Tool
MEL	Master Environment Library
MM5	Mesoscale Model (Version) 5
MPI	Message Passing Interface
MPICH	Message Passing Interface Chameleon
MRF	Medium Range Forecasting (Model)
NCEP	National Center for Environmental Prediction
NOGAPS	Navy Operational Global Atmospheric Prediction System
Raob	Radiosonde observation
SOAP	Simple Object Access Protocol
UTC	Universal Time Coordinates
VisAD	Visualization for Algorithm Development
WRF	Weather Research and Forecasting model

WRFSI	WRF Standard Initialization
XML	eXtensible Markup Language

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